Abnormal patterns of tongue-palate contact in the speech of individuals with cleft palate

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Abstract

Individuals with cleft palate, even those with adequate velopharyngeal function, are at high risk for disordered lingual articulation. This article attempts to summarise current knowledge of abnormal tongue-palate contact patterns derived from electropalatographic (EPG) data in speakers with cleft palate. These data, which have been reported in 23 articles published over the past 20 years, have added significantly to our knowledge about cleft palate speech. Eight abnormal patterns of tongue-palate contact are described and illustrated with data from children and adults with repaired cleft palate. The paper also discusses some of the problems in interpreting EPG data from speakers with abnormal craniofacial anatomy and emphasises the importance of quantifying relevant aspects of tongue-palate contact data. Areas of research requiring further investigation are outlined.

Introduction

Speech and language therapists are using electropalatography (EPG) increasingly to treat individuals with articulation disorders associated with cleft palate. Ten years ago EPG was a relatively specialist clinical technique with only a few therapists having access to it in their routine work. Recent initiatives have changed this situation. For instance, there is now a nation-wide EPG diagnostic and therapy service operating in Scotland (Gibbon, Crampin, Hardcastle et al. 1998). EPG is an important research as well as clinical tool. Researchers in Japan pioneered the application of EPG for speakers with cleft palate and have reported data from the largest group. At the time when researchers in the UK first published studies using EPG with cleft palate speakers in the late 1980s, researchers in Japan had already investigated 286 individuals with cleft palate during the previous decade (Suzuki, Michi and Yamashita 1984, Suzuki 1989, Michi, Yamashita, Imai and Ohno 1990).

Children and adults with cleft palate, even those with adequate velopharyngeal function, often have poorer articulation than their noncleft peers (Fletcher 1978) and it has been estimated that approximately 35% of such speakers have abnormal lingual articulation (Lawrence and Philips 1975). As children get older, these abnormal articulations become increasingly unlikely to resolve spontaneously and are notoriously resistant to speech therapy

(McWilliams, Morris and Shelton 1990, Noordhoff, Huan and Wu 1990, Harding and Grunwell 1993).

The accumulating evidence that EPG is an effective treatment for this clinically challenging group has been a driving force that has increased speech and language therapists' motivation to use EPG in their routine clinical work. EPG has a visual feedback facility that provides a real time display of tongue-palate contact patterns that can be used as part of a speech therapy programme. Evidence suggests that visual feedback can in some cases resolve long standing articulation difficulties that have failed to respond to previous therapy approaches (Dent, Gibbon and Hardcastle 1995, Whitehill, Stokes and Yonnie 1996, Gibbon, Hardcastle, Crampin et al. 2001). In addition, improved articulation placement can have wider benefits for the intelligibility of speech by reducing or even eliminating hypernasality and nasal emission (Dent, Gibbon and Hardcastle 1992, Whitehill et al. 1996, Sell and Grunwell 2001).

The largest EPG treatment group reported in the literature consists of 51 Japanese-speaking patients with cleft palate (Michi et al. 1990). Although there are few details available, the authors reported that of 51 patients who received visual feedback therapy with EPG, ten discontinued therapy because their speech difficulties had resolved. The remaining 41 patients had error-free speech at the sentence level following EPG therapy, but they continued to need carry-over speech therapy using approaches other than EPG. A study by Gibbon et al. (2001) of 12 children with cleft palate showed that nine made measurable gains with just four sessions of EPG therapy, whereas only one child made gains with the same number of therapy sessions without visual feedback. In addition, a number of studies report positive therapy outcomes in single cases or small groups (Michi, Suzuki, Yamashita and Imai 1986, Gibbon and Hardcastle 1989, Hardcastle, Morgan Barry and Nunn 1989, Dent et al. 1992, 1995, Michi, Yamashita, Imai, Suzuki and Yoshida 1993, Stokes, Whitehill, Tsui and Yuen 1996, Whitehill et al. 1996).

EPG is not just a therapy tool, however. EPG data can provide objective, quantifiable and clinically relevant information about lingual articulation that adds to our knowledge about speech difficulties experienced by individuals with cleft palate. Furthermore, data recorded from EPG can enhance the comprehensiveness of speech assessment and improve diagnostic accuracy in individuals who are undergoing EPG therapy. This information underpins effective remediation and provides a baseline for measuring progress over time. During assessment, information from EPG is used alongside other standard procedures including perceptually based phonetic and phonological analyses, intelligibility measures, clinical examination of the vocal tract and instrumental procedures to investigate, for example, velopharyngeal function.

EPG data can be used to confirm the accuracy of inferences made from transcription data. In a case study of a 6-year-old with cleft palate, Howard and Pickstone (1995) used EPG to confirm their auditory impression that this child's productions of alveolar and velar targets that were heard as glottal articulations, were not in reality double articulations [tʔ] or [kʔ]. These double articulations can be difficult for listeners to detect because in some cases the oral articulation is auditorily masked or hidden by the glottal plosive. The EPG data was able to confirm that no tongue-palate contact occurred simultaneously with the glottal plosive in this case.

EPG data can also provide important diagnostic information that is not readily available from transcription analyses alone (Michi et al. 1986, Gibbon and Hardcastle 1989, Hardcastle et al. 1989, Dent et al. 1995, Gibbon, et al. 1998, Gibbon and Crampin 2001, 2002). Auditory analysis can not always reveal details such as: subtle differences in articulation between phoneme contrasts (so-called covert contrasts); the precise details of place of articulation during lateralized or palatalized distortions; abnormal duration and timing of articulations; or the presence of abnormal double articulations. These details will be described in more detail in the sections that follow.

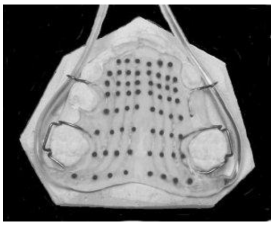
This article focuses on the contribution that EPG has made to our knowledge about abnormal patterns of tongue-palate contact in individuals with cleft palate. It has two parts. Part 1 describes EPG systems that have been used in previous studies for investigating cleft palate speech. Part 2 describes eight patterns of abnormal tongue-palate contact, which are illustrated by examples of EPG data recorded from children and adults with articulation disorders associated with cleft palate. The eight patterns are intended as a convenient summary based on EPG data reported in 23 articles on cleft palate speech published in English over the past 20 years (see Appendix 1). Some of the eight patterns have been studied widely and systematically, whereas others are based on observation and require further empirical investigation. Patterns 1-7 involve abnormal EPG configurations compared to those produced by normal speakers, whereas Pattern 8 is concerned with abnormal timing, which involves difficulties in the duration or sequencing of articulations. The relative lack of attention to timing difficulties in cleft palate speech is not because they are less frequent or have less of an impact on speech intelligibility. Rather, it is a reflection of current knowledge derived from available literature.

Part 1.

EPG systems used to investigate cleft palate speech

EPG is an instrumental procedure that records details of the location and timing of the tongue's contact with the hard palate during speech (Hardcastle, Gibbon and Jones 1991, Hardcastle and Gibbon 1997). Two commercially available versions have dominated EPG research in the field of cleft palate, and the following sections focus on describing these two systems. A British system – the EPG3 system developed at the University of Reading – has been used in the majority of cleft palate studies conducted by researchers in the UK and Hong Kong. A new Windows® version of the Reading EPG has recently been developed at Queen Margaret University College, Edinburgh, UK. The Rion EPG (Fujimura, Tatsumi and Kagaya 1973, Hiki and Itoh 1986) is used in all the studies reporting Japanese cleft palate speech. All EPG systems, including a Linguagraph system developed at the University of Canterbury, UK, by Kelly, Main, Manley and McLean (2000), share some common general features, but differ in details such as the construction of the palates, number and configuration of electrodes, and hardware/software specifications. An essential facility in the investigation of cleft palate speech is to be able to record and display EPG data simultaneously with other channels, such as the acoustic signal and oral/nasal airflow. The acoustic signal allows the researcher or clinician to play out the recorded acoustic data for perceptual analysis and to locate relevant articulation events on the waveform.

(a)



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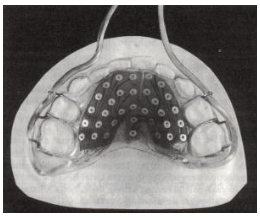


Figure 1. Photographs of Reading (a) and Rion (b) artificial palates placed on top of plaster impressions (these palates are from children who do not have cleft palate).

Artificial palates

A component of all EPG systems is a custom-made artificial palate moulded to fit the speaker's hard palate. Embedded in the artificial palate are electrodes exposed to the lingual surface. The Reading and Rion palates are made from a relatively rigid acrylic, and are held in place by metal clasps that fit over the upper teeth. A Reading and a Rion palate are shown in figure 1. The Reading palates have 62 electrodes placed according to identifiable anatomical landmarks (Hardcastle, Gibbon and Jones 1991). The electrodes are arranged in eight horizontal rows, with eight electrodes in the every row except the most anterior, which has six.

The most posterior row of electrodes on the Reading palates is located on the junction between the hard and soft palates. Placement on this junction ensures that in most English speakers some contact is registered for velar targets /k/, /ɡ/ and /ŋ /. Complete closure across the palate for velar targets is usual where they occur in close vowel contexts, such as /i/ (e.g. in the word ‘key’) and /ɪ/ (e.g. in ‘Kim’) or in /kj/ clusters (e.g. in ‘cute’). Normal speakers’ productions of velar targets tend to have minimal EPG contact in open vowel contexts, such as /ɑ/ and /a/ (e.g. in ‘car’). Lateral electrodes are located between the upper teeth and gingival border, ensuring that a lateral seal for alveolar and postalveolar stops, fricatives and affricates is recorded. There is a higher density of electrodes in the anterior (alveolar) region of the palate so events such as tongue grooving during sibilants are recorded in detail. The Rion palates have six standard electrode configurations, which are arranged in a series of hemispherical curves. There are fewer electrodes on the Rion than the Reading palates, with 30-40 electrodes being typical for children’s palates.

The fact that placement of electrodes on Reading palates is according to anatomical landmarks has been mentioned already. The Japanese system, on the other hand, selects the best fit for an individual's palate from a set of standard templates that covers a wide range of different palate sizes and shapes. The advantage of the electrode arrangement on the Rion palates is that the distances between electrodes are constant for a given size of palate. This means that it is possible to calculate area of contact and distance between electrodes. A disadvantage of the Rion palates is that, because the electrodes are not placed according to an individual speaker's palate morphology, electrodes do not always cover important areas of the hard palate such as lateral and/or velar regions.

EPG data

EPG systems that use Reading palates register characteristic patterns in normal speakers for all English lingual phoneme targets /t/ /d/, /k/, /g/, /s/, /z/, /ʃ/, /ʒ/, /tʃ/, /dʒ/, the palatal approximant /j/, nasals /n/, /ŋ/, and the lateral /l/. Varying amounts of contact are registered during relatively close vowels, such as /i/, /ɪ/, /e/, /u/, /ʊ/ and rising diphthongs, such as /eɪ/, /ɑɪ/, /oɪ/, /aʊ/ and /əʊ/. There is, however, usually little contact during open vowels, such as /ɑ/, /æ/ and /ɒ/. Articulations that have their primary constriction either further forward than the most anterior row of electrodes (e.g. dentals or labials) or further back than the most posterior row of electrodes (e.g. velars in the context of open vowels, uvular, pharyngeal and glottal sounds) do not register characteristic EPG patterns. Some EPG contact may be present during these articulations, however, due to the influence of surrounding vowels.

EPG is a particularly valuable technique for investigating cleft palate speech because it provides information about a wide range of frequent errors. Errors in cleft palate speech most frequently affect sibilant fricative and affricate targets (/s/, /z/, /ʃ/, /ʒ/, /tʃ/, /dʒ/), followed by plosive targets (/t/, /d/, /k/, /g/), then approximants (/l/, /r/, /j/, /w/) and finally nasals (/n/, /ŋ/) and vowels (Spriestersbach, Darley and Rouse 1956, Van Demark, Morris and Vandehaar 1979). All targets shown in brackets involve lingual articulation and register measurable amounts of EPG contact. In short, the technique is valuable for diagnosing almost all frequently occurring errors, particularly the obstruent consonants that are highly vulnerable to disruption in individuals with cleft palate.

Phonetic zones

Alveolar, postalveolar, palatal and velar are four phonetically relevant regions of the hard palate that can be correlated to zones on the EPG palate. This correlation makes it possible to classify articulations according to the location (i.e. place) of articulation within the oral cavity at which major events occur. Figure 2a shows how phonetic regions are located on the Reading palates, and figure 2b shows how they are located on the Rion palates. Although EPG can provide useful information about placement on the hard palate, in order to make judgements about manner of articulation (i.e. plosive, nasal, fricative, affricate, approximant), perceptual analysis of speech and information from the acoustic signal are needed.

(a)

Normal	Row	
000000	1	Alveolar
000..000	2	
0.....00	3	Post-alveolar
0......0	4	
0......0	5	
0......0	6	Palatal
0......0	7	
0......0	8	Velar

(b)

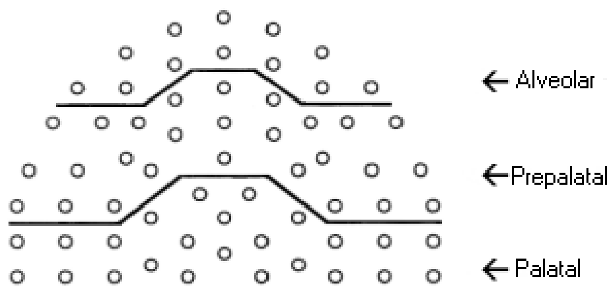


Figure 2. Location of phonetic regions on (a) the Reading and (b) the Rion palates. Note that electrodes on the Rion palates do not extend as far back as on the Reading palates.

Raw data, data reduction and annotation

EPG raw data are usually displayed as sequences of two-dimensional representations referred to as palatograms or EPG frames. Sampling rates vary from system to system. The Reading EPG3 system samples at 100 Hz, with Rion sampling at the slower rate of 64 Hz. Obviously, slower sampling rates produce a less detailed record of tongue activity. Observation of raw data reveals features such as the location of tongue palate contact (spatial information), and the timing of tongue movement (temporal information). Although informative, raw data are unwieldy with 60-100 EPG frames produced for every second of speech recorded. As a result, researchers are continuously devising new and better methods of data reduction (Hardcastle, Gibbon and Nicolaidis 1991, Byrd, Flemming, Mueller and Tan 1995, Gibbon and Nicolaidis 1999). Indices allow reduction of EPG data to numerical values, which can be analysed statistically.

An alternative approach to data reduction is to use an EPG classification system. Japanese researchers (Suzuki 1989, Yamashita, Michi, Imai, Suzuki and Yoshida 1992) developed a classification system, which they have used extensively in their investigations of cleft palate speech. The system involves matching a particular EPG pattern, usually the frame of maximum contact during the production of a target phoneme, to a set of 8 standard configurations. Gibbon, Whitehill, Hardcastle, Stokes and Nairn (1998) developed an alternative scheme in a cross-language (English/Cantonese) EPG study. Here, the frame of maximum contact was judged in a binary classification according to whether or not there was constriction in various regions of the palate.

Identifying abnormal EPG patterns

Some of the problems involved in identifying abnormal patterns in individuals with craniofacial anomalies warrant brief commentary. Distinguishing normal from abnormal EPG patterns in these situations is not a straightforward task. Part of the difficulty is the fact that we do not have a good definition of the range of 'normal' EPG patterns in cleft palate speakers. One reason for this is that individuals with cleft palate who have highly intelligible, error-free speech, have not been investigated with EPG.

Although there are no studies reporting EPG patterns in error-free cleft palate speakers, many studies have reported EPG data for children and adults with normal craniofacial anatomy and normal speech production (see Gibbon 1999 for a summary). Knowledge of normal patterns is essential when identifying abnormal patterns. The location of the anterior groove for sibilants in normal speakers is often not in the midline, for example, and can be located to the right or to the left. As a result, groove asymmetry is not necessarily an abnormal pattern in cleft palate speech. Likewise, contact patterns for alveolar stops, particularly /t/ targets in syllable final position, do not always show complete closure in normal speakers and can resemble a contact pattern for /s/. Once again, incomplete closure for /t/ does not necessarily indicate an abnormal pattern. The normative data that is available in the literature can guide speech clinicians when they are judging the normality of patterns produced by individuals with cleft palate.

Caution is needed when comparing EPG data from normal and cleft palate speakers, however. The hard palates of cleft speakers (at least those who have a cleft of the alveolus) tend to be smaller, narrower, and more irregular in shape than those of normal speakers. Further, abnormal dental conditions (e.g. maxillary collapse, dental malalignment, missing teeth, ectopic eruption of teeth, supernumerary teeth and protrusion of the maxilla) as well as malocclusion are frequent in people with cleft palate. These factors will have direct effects on tongue-palate contact patterns (Peterson-Falzone, Hardin-Jones and Karnell 2001). The above points highlight the importance of taking into account individuals' craniofacial anatomy as well as normal tongue contact patterns when interpreting EPG data. It is especially important to consider anatomy, because the severity of speech problems increases with severity of cleft type (Morley 1970, Fletcher 1978, Riski and DeLong 1984, Karling, Larson and Henningsson 1993). This means that individuals with severe speech difficulties, who are likely candidates for EPG therapy, are also likely to have severe craniofacial anomalies.

Part 2.

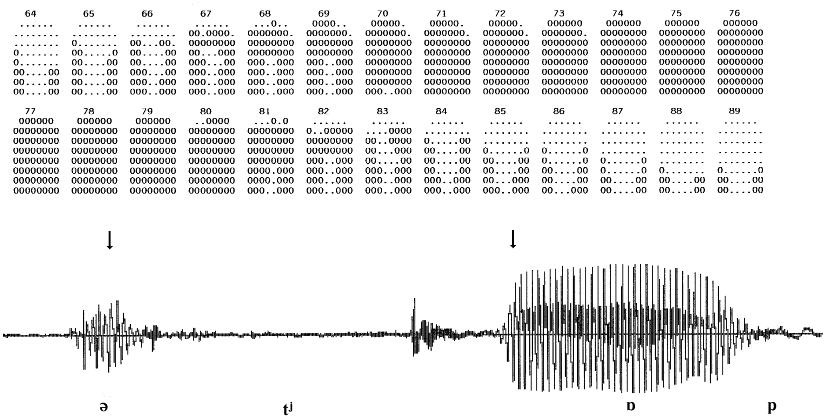
Types of abnormal tongue-palate contact patterns

The next section describes eight abnormal patterns of tongue-palate contact identified from EPG data. These patterns are illustrated with examples of EPG data from children and adults with cleft palate who have participated in projects conducted by a multidisciplinary research team based at Queen Margaret University College, Edinburgh, in collaboration with four cleft palate centres in Scotland. The EPG patterns are judged as abnormal on the basis that they have not been observed in normal speakers for the same phoneme targets. Examples from children and adults with cleft palate illustrate the eight patterns, and data from normal speakers are presented for comparison. The perceptual correlates of the abnormal EPG patterns are discussed, as are methods of data reduction that can be used to extract and quantify clinically relevant information.

Pattern 1. Increased contact

Increased tongue-palate contact is one of the most frequently observed EPG characteristics of speech produced by individuals with cleft palate, and it can affect all lingual consonant targets (Fletcher 1985, Hardcastle et al. 1989, Yamashita et al. 1992, Gibbon and Crampin 2001). Increased contact can affect vowel as well as consonant targets, and abnormal contacts during vowels are described later in Pattern 4. Figure 3a shows an example of increased contact for the phoneme target /t/ in the word 'top' produced by an 8-year-old boy with a complete cleft of the hard and soft palate. Perceptually, this was judged as palatalized, /t/ → [tʲ]. The EPG frames in figure 3a are those that occur between the two arrows above the waveform. In the child's production of this /t/ target, after the approach phase (frames 64-66), tongue-palate contact increases so that by frame 74 all electrodes on the palate are contacted. The same target produced by a normal speaker is in figure 3b, which shows well-defined contact in the peripheral lateral and alveolar regions, forming the characteristic 'horseshoe-shape' alveolar stop pattern. Compared to the normal speaker's production, the /t/ target produced by the child with cleft palate quite clearly involves increased contact. The high amount of contact shown in figure 3a is similar to a pattern referred to as maximum contact in Japanese studies. In a study of 53 speakers, Yamashita et al. (1992) found that 34% of consonants produced as palatal misarticulations and 59% of consonants produced as lateral misarticulations had maximum contact patterns.

(a) 8-year-old boy with cleft palate



(b) normal adult (male) speaker

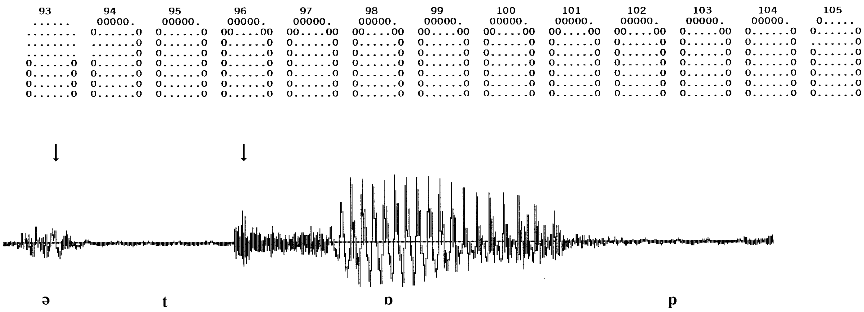


Figure 3. EPG data that illustrates Patten 1 – increased tongue-palate contact. The example in (a) shows EPG patterns during word-initial /t/ in 'a top' produced by an 8-year-old boy with a cleft palate. The EPG frames shown are those that occurred between the arrows above the acoustic waveform. A phonetic transcription of the utterance is below the waveform. Increased contact occurs throughout stop closure, with frames 71-79 having complete contact across the whole of the palate. The normal speaker's production of the same word is shown in (b), which illustrates a characteristic alveolar stop pattern for /t/.

Increased contact pattern can also be interpreted as alveolar-velar double articulations. Double articulations [tk] and [dg] have been described in EPG studies as occurring for targets /t/, /d/, /k/ and /g/ (Hardcastle et al. 1989, Dent et al. 1992, Whitehill, Stokes, Hardcastle and Gibbon 1995). These double articulations have also been identified in transcription studies, such as a longitudinal study by Harding and Grunwell (1993) that found that half of the 26 English-speaking children produced these double articulations at some stage in their phonetic development towards correct production of /t/ targets.

Although the evidence from EPG and transcription-based studies suggests that increased tongue-palate contact is relatively frequent in cleft palate speech, it is uncertain why it occurs. Hardcastle et al. (1989) discuss possible causes, notably impaired development of normal tongue function due to: scarring and subsequent lack of tactile awareness; the presence of fistulae and the possibility of compensatory actions of the tongue apex; hearing impairment; or a concomitant articulatory dyspraxia. These authors also discuss how structural abnormalities, such as abnormal hard palate size and shape, can restrict intra-oral space. This can limit the tongue's ability to make fine adjustments within the oral cavity for the production of accurate movements necessary for intelligible speech. Whitehill et al. (1995) reported the occurrence of increased contact across the palate during velar targets in two Cantonese-speaking children with cleft palate (these children's EPG patterns were similar to those in figure 9a). Both children had residual, unobturated alveolar clefts. Whitehill et al. suggested that the simultaneous alveolar contact during velars was a compensatory manoeuvre resulting from the children's attempts to block the alveolar cleft.

Pattern 2. Retraction to palatal or velar placement

One of the most frequently reported tendencies in cleft palate speech is for anterior consonants to be shifted backwards to an abnormally retracted place of articulation (Morley 1970, Lawrence and Philips 1975, Trost 1981). Errors may involve retraction to palatal placement, as occurs in Trost's (1981) middorsum palatal stops, or placement that is further back in the vocal tract at velar, uvular, pharyngeal, or glottal place of articulation. Velar targets are less likely than alveolar targets to involve placement errors (Spriestersbach et al. 1956). Nevertheless, when errors do affect velar targets, the errors tend to be similar to those affecting alveolar targets.

It is not surprising to find that EPG patterns in individuals with cleft palate often involve retracted placement. This type of articulation abnormality has been reported in EPG studies of English (Gibbon and Hardcastle 1989, Hardcastle et al. 1989, Gibbon and Crampin, 2001), Japanese (Yamashita et al. 1992), and Cantonese (Whitehill et al. 1995, 1996) speakers with cleft palate. Yamashita et al. (1992) investigated EPG patterns in 53 Japanese children and young adults and found that 33% of palatal misarticulations and 32% of lateral misarticulations had retracted placement involving complete constriction in the posterior region of the palate.

Retracted placement is illustrated in figure 4a, which shows EPG patterns for the /t/ target in the word ‘top’ produced by a 14-year-old girl with cleft palate. Listeners transcribed this child’s production of /t/ as a middorsum palatal stop [c]. Instead of a normal alveolar placement, this child has no contact in the anterior (alveolar) region and an abnormally high amount of contact in the posterior (palatal/velar) regions. A normal adult speaker’s production of the same target is in figure 4b.

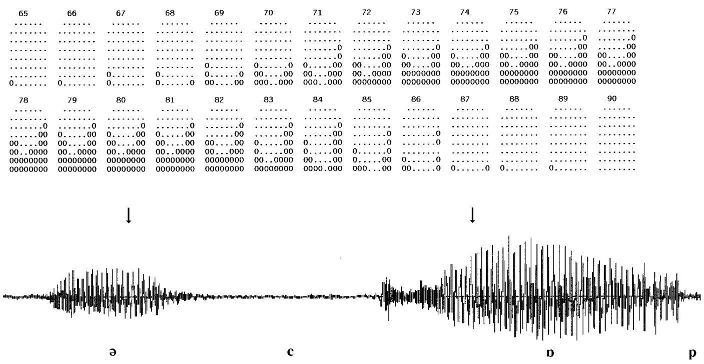
Retracted patterns can have a central posterior groove in addition to palatal or velar placement. This is most often found during alveolar and postalveolar fricative targets that are heard as palatal or velar fricatives (Michi et al. 1990, Yamashita et al. 1992, Howard 1998, Howard and Pickstone 1995). Yamashita et al. found that 25% of Japanese palatalized productions – almost all of which affected targets /s/, /ʃ/, /dz/, /ts/ – involved retracted placement and a central groove. Howard and Pickstone (1995) described contact patterns produced by a 6-year-old girl with a repaired cleft of the hard and soft palate. Contact patterns for targets /s/, /z/, /ʃ/ and /ʒ/ produced by this child were transcribed as palatal fricatives, and typically involved retracted placement, a fairly broad central groove and a wide band of side contact from postalveolar to the front of the velar region.

Overuse of the tongue dorsum

X-ray evidence suggests that increased contact and retracted placement (patterns 1 and 2) involve overuse of the tongue dorsum. Michi et al. (1990) conducted lateral x-ray tracings during abnormal productions of articulations with increased/retracted EPG patterns, and found that the posterior tongue dorsum was elevated to make contact with the posterior part of the hard palate and the anterior soft palate. This finding is consistent with studies reporting that children with cleft palate have a tendency to overuse the tongue dorsum, maintaining a generally high tongue position relative to the palate and articulating with the back of the tongue (Morley 1970, Lawrence and Philips 1975, Golding-Kushner 1995).

It has been postulated that children with cleft palate may overuse the tongue body to aid velopharyngeal function, a phenomenon sometimes referred to as ‘lingual assistance’ (Trost 1981). In this manoeuvre, a high tongue body tongue posture assists in attaining velopharyngeal closure for high-pressure consonants. The strong tendency to articulate with the back of the tongue may be associated with ongoing velopharyngeal dysfunction. Although this is one explanation, overuse of the tongue dorsum has been observed in children with early palatal closure and velopharyngeal competence (Yamashita and Michi 1991). They postulated that a high tongue posture may be a habitual pattern established at a very early age before palate surgery has taken place.

(a) 14-year-old girl with cleft palate



(b) normal adult (male) speaker

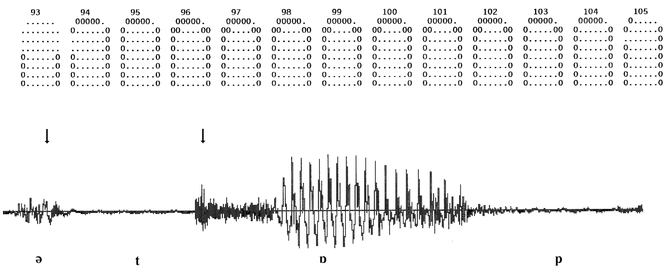


Figure 4. EPG data in (a) illustrates retracted placement. This example shows target /t/ in 'a top' produced by a 14-year-old girl with a cleft palate. Retracted placement for /t/ is evident by tongue-palate contact in the posterior region. The normal speaker's production in (b) has a characteristic alveolar stop pattern for the same target.

A negative consequence of increased tongue-palate contact is that these patterns affect the individual's ability to brace the lateral margins of the tongue. Normal speakers produce anterior consonants such as /t/, /d/, /n/, /s/ and /z/ by a combination of lateral bracing and an upward movement of the tongue tip/blade to the alveolar ridge, resulting in a characteristic horseshoe shape EPG spatial configuration (see figures 3b and 4b). Children with cleft palate who have increased contact may have difficulties in the control of the lateral and medial regions of the tongue. Stone, Faber, Raphael and Shawker (1992) suggested that control of the lateral margins of the tongue is essential for normal speech production, because lateral anchorage gives stability to the whole of the tongue. The implication is that if children have consistently increased contact, then this will have a significant and detrimental impact on their development of speech motor control.

Pattern 3. Fronted placement

The third abnormal pattern involves a more fronted placement than occurs in normal speech. Although fronting is undoubtedly much less frequent than backing in cleft palate speech, this pattern affects velar targets that are produced as middorsum palatal stops. A fronted pattern usually involves contact in the palatal as well as the velar region of the palate for phonemic targets /k/, /ɡ/ and /ŋ/. For example, Hardcastle et al. (1989) described a child whose EPG patterns for velar targets had more contact in the palatal region than a normal speaker, despite this child having perceptually correct velars. Gibbon and Crampin (2001) reported a similar pattern for velar targets produced as middorsum palatal stops in the speech of an adult with cleft palate.

Reduced alveolar-velar placement separation

The combination of retracted placement for alveolar targets (e.g. figure 4a) and fronted placement for velar targets can result in reduced, or no alveolar-velar placement separation. In normal speakers, alveolar and velar targets are separated by quite different places of articulations. Gibbon and Crampin (2001) reported an adult with cleft palate who had reduced placement separation for /t/ and /k/ targets, which were heard as middorsum palatal stops [c]. This speaker's reduced separation is illustrated in figure 5, which shows centre of gravity values representing placement on the hard palate in the front-to-back dimension. Higher centre of gravity values indicate a more forward placement, with lower values reflecting more posterior placement. Compared to two normal speakers (N1 and N2), the speaker with cleft palate (CP) has low values for /t/ targets indicating retracted placement. Values for /k/ targets show the opposite trend, indicating a more fronted placement than normal. The figure clearly shows how CP's retracted alveolar targets and fronted velar targets act together to reduce placement separation. Although separation was reduced, statistical analysis revealed that CP had a significant placement distinction for alveolar and velar targets, although the perceptual analysis indicated placement neutralisation.

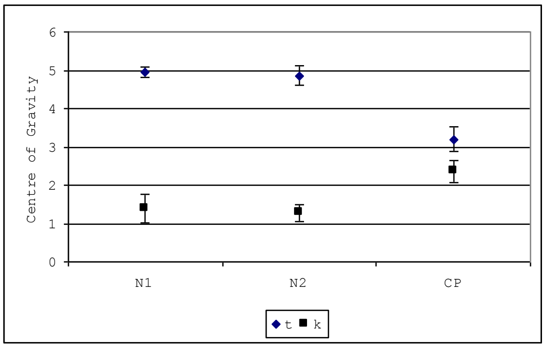


Figure 5. Graph showing reduced placement separation for /t/ and /k/ targets, as measured by the centre of gravity index. The figure shows mean and standard deviation of centre of gravity values for two normal adult speakers (N1 and N2) and an adult with cleft palate (CP).

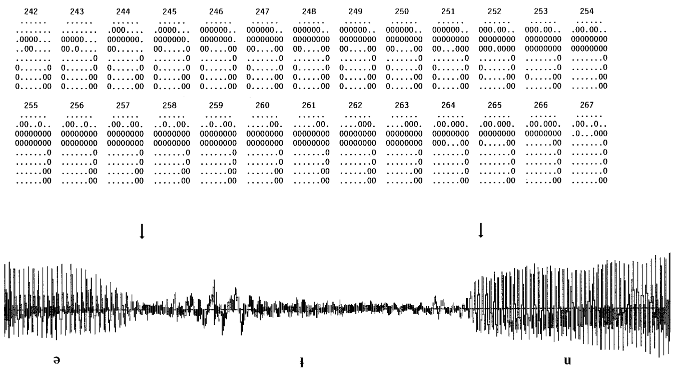
Gibbon and Crampin (2001) argued that for research and clinical purposes it is important to distinguish between reduced placement separation on the one hand (as illustrated in figure 5) and placement contrast neutralisation on the other. Neutralisation is the predicted outcome of the application of phonological process rules, such as backing alveolar targets to velar placement. Evidence of an articulatory distinction between phonemic contrasts, such as occurs in reduced separation, differentiates speech errors that are phonetic in origin from those that have a phonological basis (McWilliams et al. 1990, Grunwell 1993, Sell, Harding and Grunwell 1994). Differentiating phonetic and phonological speech errors has therapeutic as well as diagnostic implications. Phonetic errors are viewed as requiring motor-oriented therapy, whereas phonological errors require an approach focusing on linguistic conceptualisation and organisation (Bernthal and Bankson 1988). This is a good example of how EPG data can provide important diagnostic information not available from standard perceptual assessments.

Pattern 4. Complete closure

Complete closure across the palate is an abnormal pattern affecting targets that in normal speakers have a groove. The groove allows air to flow out of the mouth with a central airstream. Two sound classes can have this error pattern. The first are sibilant targets (/s/, /z/, /ʃ/, /ʒ/), the second are the close vowels (/i/, /ɪ/) and approximant /j/. Where complete closure affects sibilant targets there is evidence from the acoustic signal and from perceptual analysis of friction, but the EPG patterns show complete constriction. With complete constriction across the palate, the possibility of central release of air is reduced, and there are two possible routes for air to escape. The first is around the lateral margins of the tongue producing lateral friction, the second is through the nose resulting in nasal escape of air. It is not possible, of course, to know from the EPG trace alone where air is escaping.

Complete closure across the palate during sibilant targets often results in the production of lateral fricatives [ɬ], [ɮ] (see also discussion of lateral fricatives involving Pattern 1). Figure 6a shows EPG patterns from a 7-year-old boy with a cleft palate producing a target /ʃ/ in the phrase ‘a shoe’, transcribed as a lateral fricative [ɬ]. In this example, there is complete contact across the palate in the alveolar/postalveolar region, and incomplete lateral contact on the left side. It is likely that the air is escaping out of the left side into the buccal cavity due to incomplete lateral seal on this side, but this information is only indirectly inferred from the EPG patterns, and further diagnostic tests would be needed to confirm this. Figure 6b shows a normal adult speaker’s production of the same target.

(a) 7-year-old boy with cleft palate



(b) normal adult (male) speaker

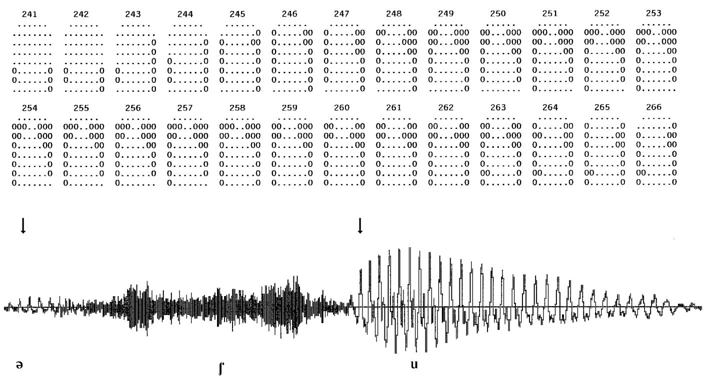


Figure 6. The example in (a) shows complete closure during a sibilant target, heard in this case as a lateral fricative [ɬ]. The target is /ʃ/ in ‘a shoe’. The normal speaker in (b) has a

central groove in the postalveolar region, whereas the speaker with cleft palate has complete closure across the palate.

The EPG pattern produced by the normal speaker clearly shows a central groove located in the postalveolar region of the palate.

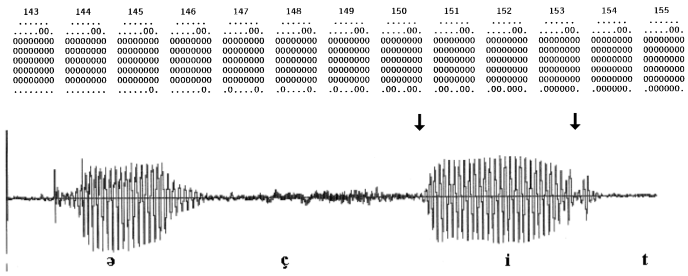
The EPG configuration involved in abnormal lateral fricatives can vary enormously. A study by Yamashita et al. (1992) showed that only a minority of these misarticulations involved alveolar contact, such as illustrated in figure 6. They found that 32% of lateral misarticulations involved contact in the posterior region (retracted placement) and 68% involved contact across the whole of the palate (increased contact). Lateral fricatives are almost always associated with complete contact across the palate, however.

Complete EPG closure for sibilant targets can also result in nasal escape of air and the production of posterior nasal fricatives. Nasal misarticulations, similar to Trost's (1981) posterior nasal fricatives, have been described as occurring in Japanese speakers with cleft palate (Abe 1987). Yamashita et al. (1992) described three individuals whose speech contained nasopharyngeal misarticulations, all of which were produced with complete closure across the palate. Dent et al. (1992) described a 9-year-old child with a cleft palate who produced complete contact in the velar region during /s/ and /z/ targets, which were heard by listeners as nasal fricatives.

EPG researchers have reported that some speakers with cleft palate have complete contact across the palate during their productions of high vowels and the approximant /j/ (Howard personal communication, Michi et al. 1990, Yamashita and Michi 1991). Patterns that have complete contact for vowel targets typically also involve increased contact (see Pattern 1). Figure 7a illustrates complete contact during the high vowel /i/ target produced by a 9-year-old girl with cleft palate. Figure 7b shows a normal speaker's production of the same vowel, which has extensive lateral contact but not complete contact in the central region of the palate. The pattern produced by the normal speaker reflects a high tongue position combined with a central air stream, which is typical during vowels such as /i/, /ɪ/ and the approximant /j/.

The clinical relevance of complete contact across the palate during vowels and /j/ relates to the degree of hypernasality during vowels. Hypernasal resonance perceived during the production of vowels and some approximants is one of the qualities that makes cleft palate speech perceptually deviant (Trost-Cardamone and Bernthal 1993). Although previous studies have shown that individuals with cleft palate produce vowels less distinctly than normal speakers (Cullinan and Counihan 1971), the source of the loss of vowel intelligibility has not been established (Peterson-Falzone et al. 2001). One possible source is that complete oral constriction results in increased hypernasality of vowels, which in turn has a detrimental effect on their intelligibility.

(a) 9-year-old girl with cleft palate



(b) normal adult (male) speaker

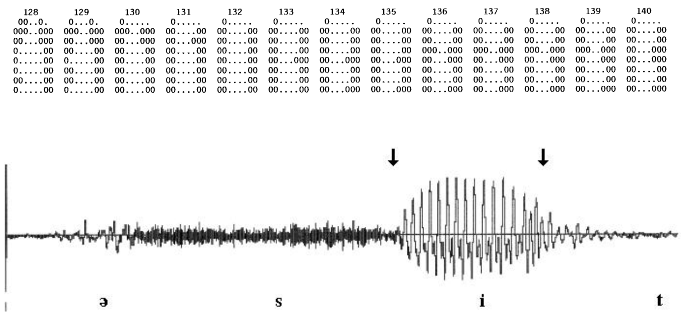


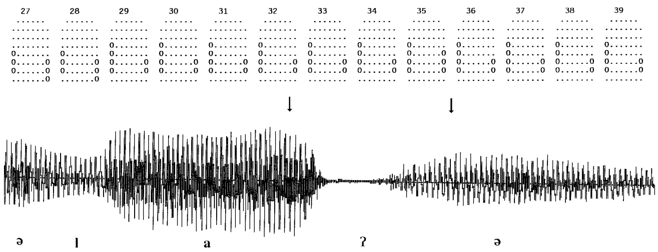
Figure 7. EPG data in (a) shows complete contact across the palate during /i/ in the word ‘seat’, produced by a 9-year-old girl with a cleft palate. The normal speaker has lateral contact, but contact is not complete in the central region.

Pattern 5. Open pattern

As discussed earlier, a type of compensatory error involves anterior targets produced as pharyngeal and glottal articulations. These articulations register minimal tongue-palate contact and are referred to as having an ‘open pattern’. This pattern occurs where there is little or no tongue-palate contact in a context where a normal speaker would produce a characteristic EPG pattern. The open pattern has been reported in English (Dent et al. 1995, Gibbon, Whitehill et al. 1998), Cantonese (Stokes et al. 1996), and Japanese speakers with cleft palate (Yamashita et al. 1992). Articulations that have their primary constriction further back than the most posterior row of electrodes (e.g. uvular, pharyngeal and glottal sounds) are most often associated with an open pattern. However, articulations further forward than the most anterior row of electrodes (e.g. dentals or labials) may also be associated with a minimal contact pattern.

Figure 8

(a) 9-year-old boy with history of velopharyngeal incompetence



(b) normal 12-year-old (male) speaker

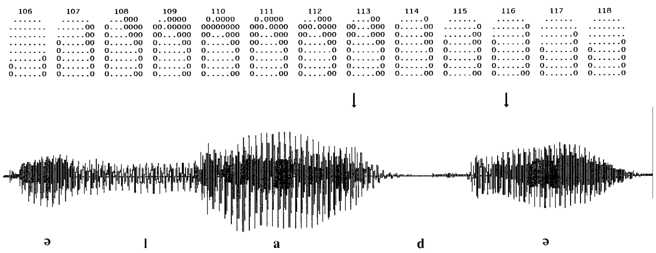


Figure 8. EPG data in (a) illustrates a minimal contact pattern, which involves fewer than normal contacted electrodes. The target is /d/ in word-medial position in 'ladder', produced by a 8-year-old boy with a history of velopharyngeal incompetence. The target /d/ was transcribed as a glottal stop [ʔ]. The normal child's production in (b) shows a normal alveolar stop pattern for the same /d/ target.

Figure 8a illustrates an open pattern during a /d/ target in the word 'ladder'. In this example, an 8-year-old boy with a history of velopharyngeal incompetence produced the target with only a few electrodes contacted, all of which were located in the lateral region. This child's production of 'ladder' was transcribed [laʔə]. In contrast, the example from the normal child in figure 8b shows the characteristic horseshoe shape of a normal /d/, although closure has a short duration similar to an alveolar tap articulation.

Minimal contact patterns are unlikely to be due to impaired motor ability, such as poor innervation of the tongue per se. Rather, if a child produced predominantly glottal and pharyngeal articulations, then motor control of the tongue tip/blade and tongue body may have failed to develop in the normal way through lack of experience of normal movement patterns.

Glottal and pharyngeal errors are classic compensatory speech errors learned as a strategy to impound air and maintain phonological contrasts, and as a result these speech errors are prime targets for therapy with EPG if other techniques have failed to resolve the difficulty.

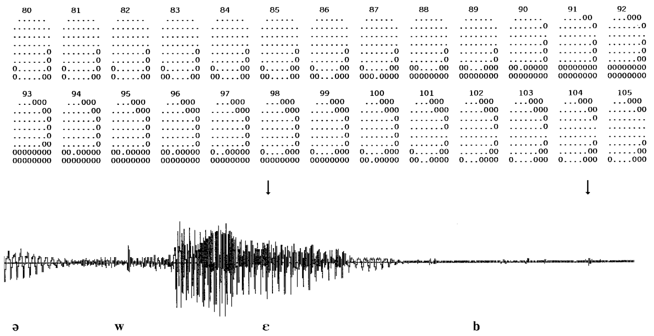
Pattern 6. Double articulations

Abnormal double articulations have been identified in many studies of cleft palate speech (Morley 1970, Trost 1981, Stengelhofen 1989, McWilliams et al. 1990, Grunwell, 1993, Sell et al. 1994). Double articulations, which Trost (1981) terms coarticulations or coproductions, involve ‘one manner of production with simultaneous valving at two places of production’ (Trost 1981: 233). A study by Gibbon and Hardcastle (1989) described a previously unreported type of articulation in cleft palate speech that involved simultaneous bilabial and lingual closure during production of labial targets. These double articulations have been termed labial-lingual double articulations (Gibbon and Crampin 2002).

A recent study (Gibbon and Crampin 2002) investigated labial-lingual double articulations in a group of 27 speakers with cleft palate. Although bilabials had not been identified in perceptual analysis as abnormal productions in any of the individuals studied, three speakers consistently produced these double articulations for bilabial targets. The configuration of tongue-palate contacts involved in the lingual component differed in each of the three speakers – one speaker had velar constriction, another had alveolar constriction, and the third had simultaneous alveolar-velar constriction.

One type of labial-lingual double articulation involves bilabial closure occurring simultaneously with the tongue body making contact against the palate in the velar region, producing a labial-velar double articulation – [pk] and [bg]. Figure 9a is an example of a labial-velar double articulation produced by a 9-year-old boy with a cleft palate (see also Dent et al. 1992, Gibbon and Crampin 2002). The target /b/ is in word-final position in the word ‘web’. Figure 9b shows the same word produced by a typically developing child of a similar age. The typically developing child shows some contact in the lateral region of the palate, which is normal in the context of bilabial following an /ɛ/ vowel (as occurs in ‘web’). In contrast, the child with a cleft palate shows complete closure across the palate in the velar region, which occurred simultaneously with bilabial closure. These labial-velar double articulations were not detected perceptually during single word productions, although listeners sometimes detected velar substitutions for labial targets during connected speech. The contact patterns in figure 9a also involve asymmetrical lateral contact that extends into the alveolar region. This was a consistent feature during velar articulations in this child, who had a residual alveolar fistula. As suggested by Whitehill et al. (1995), anterior contact during velars may be a compensatory manoeuvre adopted in order to block a fistula.

(a) 9-year-old boy with cleft palate



(b) normal 12-year-old (male) speaker

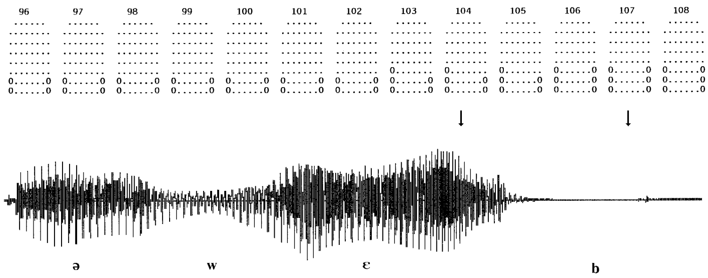


Figure 9. An example of a labial-velar double articulation produced by a 9-year-old boy with cleft palate is shown in (a). The target is word-final /b/ in 'a web'. The patterns involve complete contact across the palate in the velar region. This velar constriction occurred simultaneously with lip closure. In contrast, the normal child's production in (b) shows minimal contact for the same target, with some lateral contact in the posterior region due to the vowel context.

Gibbon and Crampin (2002) speculated on how labial-velar double articulations might become established. They noted that a strong backing pattern involving velar substitutions for bilabial targets occurred at an early age in some speakers who later produced labial-velar double articulations (Gibbon and Hardcastle 1989, Dent et al. 1992). The velar substitution stage was followed by a period of variable productions where perceptually correct bilabials occurred some of the time, and velar substitutions occurred at other times. It is possible that following a period of substituting velars for bilabials, some children superimpose labial closures onto existing lingual closures for bilabial targets. The addition of bilabial closure onto an existing closure could occur spontaneously, or following a period of speech therapy. Golding-Kushner (1995) notes that double articulations, such as [pʔ], can develop in the speech of individuals who originally had glottal replacement (e.g. /p/ targets produced as a substituted glottal stop [ʔ]), and were instructed in speech therapy to produce lip closure but were inadvertently not given guidance about correct airstream management.

	0	0	0	0	0	0	
5	5	5	0	0	0	0	5
5	5	5	0	0	0	5	5
5	5	0	0	0	0	5	5
5	3	0	0	0	0	0	5
5	0	0	0	0	0	0	5
5	0	0	0	0	0	1	5
5	4	0	0	0	0	5	5

Adult (normal)
VI = 3.2

	0	0	0	0	0	0	
0	0	0	0	0	0	1	3
3	4	1	0	0	3	5	5
5	5	2	0	0	1	5	5
5	5	0	0	0	0	4	5
5	4	0	0	0	0	4	5
5	5	0	0	0	0	5	5
5	2	0	0	0	0	4	5

Child (normal)
VI = 12

	0	0	0	0	0	0	
1	2	2	2	2	3	3	2
3	5	5	4	4	4	5	5
5	5	3	3	3	4	4	5
0	0	0	0	0	0	0	5
1	0	0	0	0	0	0	4
3	1	0	0	0	0	2	5
2	1	0	0	0	0	5	5

Child (cleft palate)
VI = 21.71

Figure 10. EPG frames showing variability index (VI) values for the frame of maximum contact over five repetitions of /ʃ/ in different vowel contexts. Out of the three speakers, the normal adult is the least variable, with the cleft palate speaker having the highest VI value. Shading indicates frequency of electrode contact (maximum = 5).

Pattern 7. Increased variability

EPG patterns in speakers with cleft palate have been found to be highly variable (Hardcastle et al. 1989, Howard 1998, Stokes et al. 1996, Whitehill et al. 1996, Shannon 2001). Hardcastle et al. (1989) noted highly variable EPG patterns in the speech of the two children they described. This variability was evident over repetitions of the same word in both the location of contact across different regions of the palate and the amount of contact, which ranged from partial constriction to full closure. Patterns were also variable when the same target was produced in different vowel and consonant environments.

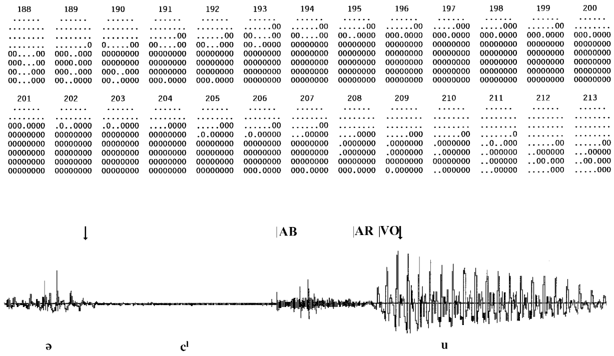
Variability of EPG patterns can be quantified using a variability index (Farnetani and Provaglio 1991). This index is a useful way of capturing the extent of variability over successive repetitions of the same word (e.g. Gibbon, McNeill, Wood and Watson 2003), over the same target in different vowel environments (e.g. Shannon 2001), or during a course of speech therapy (e.g. Gibbon et al. 2003). A variability index value of 0 indicates absolute invariance, so the higher the value the more variable the EPG patterns (maximum value is 50).

Figure 10 is from Shannon (2001) and shows variability index values calculated for five repetitions of word-initial /ʃ/ targets in different Scottish vowel contexts (/u/, /i/, /ɪ/, /o/, /ɔ/). The variability index was calculated from the EPG frame of maximum constriction during the friction period. The figure shows data from two normal speakers (an adult and a child) and a 7-year-old boy with cleft palate (the data in figures 6 and 10 are from the same child). The number of times each electrode was contacted (maximum = 5) is shown on the palate diagrams, and shaded accordingly. The variability index values reveal that the normal adult has the least variable EPG patterns for /ʃ/, with the lowest variability index value of 3.2. The normal child has more variable patterns than the adult, and this increase is reflected in the higher index value of 12. The child with cleft palate produced the most variable EPG patterns in this example, with an index value of 21.71.

Pattern 8. Abnormal timing

EPG can register important details about abnormal timing of articulations, such as the exact duration of segments and the precise timing of articulations. A child with cleft palate, described by Howard (1993) was found to manipulate stop closure duration to signal a phonemic contrast. In this single case study, a 6-year-old girl with cleft palate contrasted voiceless plosives with their voiced counterparts by consistently using a ‘significantly longer closure phase prior to the aspirated release for /t/ and /k/ targets compared to /d/ and /g/ targets’ (Howard 1993: 314). Although this strategy was unsuccessful in the sense that listeners could not detect the distinction, nevertheless, it revealed that the child was intending and attempting to mark the voicing distinction.

(a) 36-year-old male with cleft palate



(b) normal adult (female) speaker

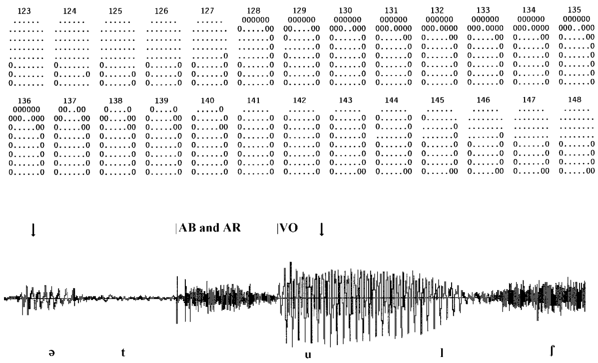


Figure 11. An illustration of abnormal timing during the release of target /t/ produced by an adult with cleft palate (Gibbon and Crampin 2001). The acoustic signal shows the target /ə tul/ extracted from the phrase ‘a toolshed’. Articulatory release (AR) as shown on the EPG and the acoustic stop burst (AB) occur simultaneously (frame 136) in the normal speaker, with voice onset (VO) occurring 70 ms later (frame 143). The acoustic burst (frame 203) produced by the speaker with cleft palate involves lateral release, followed by lateral friction. The EPG shows complete contact for 70 ms after AB, with the EPG release (AR) at frame 210. The /t/ produced by the speaker with cleft palate was judged perceptually as a middorsum palatal stop with lateral release [c^{l}].

Details of abnormal timing of stop releases produced by an adult with cleft palate were studied using EPG and acoustic analysis by Gibbon and Crampin (2001). They studied lateral release of /t/ and /k/ targets produced by an adult with cleft palate (figure 11). Lateral release can occur as a secondary feature of lingual stops (Albery 1991), but this feature has received little attention in the cleft palate literature. This lack of research is surprising because lateral release affects the quality of the acoustic cues that listeners use to identify place of articulation, with the result that abnormal lateral release is likely to have an adverse effect on speech intelligibility.

Figure 11b shows that in the normal speaker, the timing of the acoustic burst (AB) and articulatory release (AR) occurs almost simultaneously at EPG frame 136. In contrast, figure 11a shows that the speaker with cleft palate has an abnormal timing of the release pattern. Release does not occur simultaneously with the acoustic burst, but instead it occurs towards the end of the aspiration period. The acoustic burst is at EPG frame 203, but complete closure is maintained until frame 210, some 70 ms after the acoustic burst. The EPG data suggested that the release was lateral, with varying degrees of the aspiration period involving lateral friction and the rest having a central airstream.

Future Directions

EPG data published over the past 20 years have added significantly to our knowledge about articulation difficulties associated with cleft palate but there remain significant gaps in our knowledge. One is the lack of studies investigating tongue-palate contact patterns in speakers who have achieved ‘normal’ speech despite having a cleft palate. Their tongue-palate contact patterns would be different from speakers with normal vocal tracts and we need to determine the nature and extent of these differences.

We also lack knowledge about contact patterns for consonant cluster targets, which are relatively under-reported in the literature and worthy of further investigation. There is strong evidence that children with articulation difficulties associated with cleft palate experience particular problems with sequencing the movements involved in consonant clusters (Spriestersbach, Moll and Morris 1961, Bzoch 1965). Two children’s EPG patterns for consonant clusters were described by Hardcastle et al. (1989). These authors found that for both children, their ‘failure to achieve precise target movements in the single word items became increasingly obvious in the more complex sequences with consonant clusters’ (Hardcastle et al. 1989: 158). The need to investigate consonant clusters in more individuals with cleft palate was highlighted by Peterson-Falzone et al. (2001), who thought it would be valuable to know the extent to which errors involve distorted patterns, and to what extent elements of cluster sequences are omitted.

We need to know which abnormal contact patterns respond to therapy. Previous studies have reported the successful use of visual feedback with EPG to remediate some abnormal patterns, such as retracted placement, minimal contact, and complete contact for sibilant targets (Michi et al.1986, 1993, Dent et al. 1995, Whitehill et al. 1996, Gibbon et al. 2001). Not all of the eight patterns described here have been reported as therapy targets, however. Therapy for lateral release of stops, complete closure during vowels, increased contact, variability, and fronted placement for velars has not yet been reported. It is not certain if these patterns could change with therapy, or whether changes would result in measurable improvements in speech intelligibility.

It is logical to predict that speech therapy will be more effective for 'active' rather than 'passive' speech errors. Active errors are the result of abnormal learning, as opposed to 'passive' errors that are the direct result of ongoing vocal tract anomalies (e.g. Hutters and Bronsted 1987). Active errors include the production of double articulations and also backing of anterior consonants (Sell and Grunwell 2001). Not all the EPG error patterns described in previous sections are necessarily due to abnormal learning, however. Some may be the result of physiological limitations such as velopharyngeal dysfunction, dental or occlusal abnormalities or palatal fistulae. For example, crossbite or dental abnormalities could result in an inability to form the lateral seal needed for the production of normal anterior stops and sibilants. As a result, alveolar targets may be unavoidably distorted and not easily amenable to improvement through speech therapy. Further research into identifying abnormal contact patterns that respond positively to EPG therapy will assist speech and language therapists in providing the best quality health care for their clients.

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Appendix 1. EPG Studies of Cleft Palate Speech

Author/s	Year	Lang	N	Age
Dent, Gibbon and Hardcastle.	1992	Eng	1	9
Dent, Gibbon and Hardcastle.	1995	Eng	5	8-20
Fletcher.	1985	Eng	1	38
Gibbon and Crampin.	2001	Eng	1	36
Gibbon and Crampin.	2002	Eng	27	5-62
Gibbon, Crampin, Hardcastle, Nairn, Razzell et al.	1998	Eng	2	9 & 12
Gibbon and Hardcastle.	1989	Eng	1	13
Gibbon, Hardcastle, Crampin, Reynolds, Razzell et al.	2001	Eng	12	5-18
Gibbon, Whitehill, Hardcastle, Stokes and Nairn.	1997	Eng/ Can	10 Eng 10 Can	4-36
Hardcastle, Morgan Barry and Nunn.	1989	Eng	2	8 & 10
Howard.	1993	Eng	1	6
Howard	1998	Eng	1	13
Howard and Pickstone.	1995	Eng	1	6
Michi, Suzuki, Yamashita and Imai.	1986	Jap	1	6
Michi, Yamashita, Imai and Ohno.	1990	Jap	98	3-18+
Michi, Yamashita, Imai, Suzuki and Yoshida.	1993	Jap	6	4-6
Stokes, Whitehill, Tsui and Yuen.	1996	Can	2	5 & 7
Suzuki.	1989	Jap	93	3-18+
Suzuki, Michi and Yamashita.	1985	Jap	10	5-12
Whitehill, Stokes, Hardcastle and Gibbon.	1995	Can	2	5 & 7
Whitehill, Stokes and Yonnie.	1996	Can	1	18
Yamashita and Michi.	1991	Jap	3	4-5
Yamashita, Michi, Imai, Suzuki and Yoshida.	1992	Jap	53	4-20

Key: N = number of subjects reported; Eng = English; Jap = Japanese; Can = Cantonese.

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